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A COMPARISON OF PHOTOINTERPRETIVE AND DIGITAL PRODUCTION METHODS FOR FOUR KEY REMOTE SENSING-BASED INFORMATION PRODUCTS

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Abstract

This paper evaluates the costs of producing four remote sensing-based information products: timber volume estimate tables, Level II land use/land cover maps, soil maps, and vegetative cover maps. We evaluate two production methods for each product, one based on digital processing of satellite data, and the other on conventional photointerpretation of aircraft data. For each product, we compare the two strategies' production costs (including data acquisition, "ground truthing," interpretation, compilation, and printing charges) and their performance (as measured by accuracy and timeliness). Each of the production methods reviewed has been demonstrated--either operationally or experimentally--and the costs, timeliness and other performance estimates presented are based on observations made in practice. Our results show that for these products, satellite-based production results in significant cost and timeliness improvements at the cost of a loss in accuracy.

INTRODUCTION

Because individual state agencies typically lack the resources for machine processing of satellite remote sensing data,

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this data might be of widest benefit to state agency users if it were processed at a shared facility. Our research team has studied the feasibility of such a facility[1] by (1) identifying twenty-seven, remote sensing-based "priority" information products of wide utility to state agencies (in a five-state, midwestern region: Illinois, Iowa, Minnesota, Missouri, and Wisconsin); (2) determining from a user survey a useful coverage area, update frequency, number of satellite-derivable classes contained, and scale for each product; and (3) estimating the costs and performance of one, regional processing center producing these products.

This paper explores one element of a system cost and performance analysis. To prepare for analyzing systems to produce the priority products, we need information on how these products have been produced in the past. We found sufficient information for four of the twenty-seven priority products to compare "operational" methods using traditional photointerpretive techniques with satellite-based ones using LANDSAT data and computer image processing technology. The four products are listed, and their characteristics described, in Table 1.

SUMMARY OF RESULTS

For each of the four products analyzed, Table 2 compares the operational and satellite-based production methods. More detail, and references for the results presented in this Table are included later in this paper. Table 2 displays comparisons of inputs required; data gathering and processing procedures; and cost, time, and classification accuracy estimates.

In the case of the first of the four products, a timber volume estimate table, Table 2 shows that digital interpretation and classification of satellite imagery of forested areas, when coupled with multistage sampling, not only significantly improve the accuracy of timber volume estimation but also reduce costs at least tenfold. The savings are effected by lessening aircraft coverage requirements by taking advantage of synoptic satellite imagery for sample stratification. The increase in accuracy results from determining a good sampling scheme from the statistical theory of sampling.

Level II Land Use/Land Cover mapping also benefits marginally from satellite data and digital processing (on LARSYS) at the 1:24,000 scale. However, at the 1:250,000 scale, no cost change results with satellite data. On the other hand, nearly all costs of the satellite system at this scale are computer costs, and

Table 1

PRODUCT CHARACTERISTICS FOR FOUR SELECTED PRIORITY PRODUCTS

Product	Product Scale	Area Covered by One Product	Area Over Which Product Required in Five States	Categories Per Product/ Relevant Categories Derivable From Satellite Data	Product Update Frequency
Level II Land Use Map A	1:250,000	19,490 km^2	entire area 835,530 km^2	28/28	5 years
Level II Land Use Map B	1:24,000	155 km^2	urban areas (<5% of total)	16/16	5 years
Vegetative Cover Type Map	1:24,000 1:250,000	155 km^2 19,490 km^2	vegetative, non-urban areas (85% of total)	20-30/15	annual
Soil Map	1:24,000	155 km^2	selected areas	30/15	20 years
Timber Volume Estimate Table	---	one forest (varies)	forested areas (31% of total)	5/5 (density)	5 years

Table 2:

SUMMARY OF COMPARISONS BETWEEN AIRCRAFT AND SATELLITE-BASED METHODS OF PRODUCING FOUR PRIORITY PRODUCTS

Product	Timber Volume Estimate Table		Level II Land Use/Land Cover Map	
	Aircraft Method	Satellite Method	Aircraft Method	Satellite Method
1. Remote Sensing and other Inputs (platform, sensor, resolution, fractional area of coverage)	available low altitude A/C coverage of 100% of state low altitude stereo; 30% (for Missouri) f points (photodots) stereoclassified (22,030 of 214,000 in Missouri) f points (photodots) measured for ground truth (13,203/ 214,000 in Missouri)	LANDSAT, 100%, 80m available high altitude, 100% at 10m low altitude, 1% of 2m ground survey 0.5%	high altitude aircraft black and white aircraft photos 10-30m	LANDSAT CCT 4 band MSS data, 80m M/A* 5% L/A 10% of urban areas
2. Processing Procedures	rough classification on A/C photos sampling on A/C photos sampling on ground	area measurement and rough classification on LANDSAT CCT's fine sampling on low altitude and ground estimation by multi-stage sampling algorithm	photo interpretation of A/C photos into land use classes compile land use data onto planimetric map base	cluster analysis of 10% of image to establish spectral signatures classify into land use classes by maximum likelihood algorithm
3. Production Cost/km²	$15.41/km² (based on 51,700 km²)	$1.47/km² (based on 4000 km²)	1:24000-$11.93/km² 1:250,000-$ .88/km²	1:24,000 $9.70/km² 1:250,000-$0.84/km²
4. Time Estimates	12 person years for 51,700 km²	5 person months for 51,700 km²	32 person-year for 5 state region (830,000 km²) at 1:250,000	1 person-year for 5 state region at 1:250,000
5. Classification Accuracy	± 20%	± 8.6%	84.9%	80 %

*Key for Table 2:

L/A = Low Altitude Aircraft
M/A = Medium Altitude Aircraft
H/A = High Altitude Aircraft
A/C = Aircraft

C = Color
CIR = Color Infrared
B&W = Black and White

COMPARISON OF PHOTOINTERPRETIVE AND DIGITAL PRODUCTION

Table 2:

SUMMARY OF COMPARISONS BETWEEN AIRCRAFT AND SATELLITE-BASED METHODS OF PRODUCING FOUR PRIORITY PRODUCTS
(continued)

Product	Soil Map		Vegetative Cover Type Map	
	Aircraft Method	Satellite Method	Aircraft Method	Satellite Method
1. Remote Sensing and other Inputs (platform, sensor, resolution, fractional area of coverage)	low altitude aircraft stereo black and white photos. 2-3.3m	LANDSAT CCT MSS data 4 bands. 80m High altitude A/C and low altitude A/C need to verify.	low and medium altitude aerial photography CIR/C/CIR ~2m resolution total coverage of area	LANDSAT-MSS Digital and Image Skylab (if available) RB-57 and U-2 photography C/CIR L/M/H A/C C & B/W 80m - 2m
2. Processing Procedures	stereoscopically review area delineate soil types on aerial photos of area delineate slopes and erosion areas field check edit and compile map	train computer to recognize soil class spectral signatures point-by-point classify CCT LANDSAT scene output classified soil map	visual interpretation of photos, intensive field survey on ground preliminary survey by automobile	conventional photointerpretation and interactive digital processing techniques
3. Production Cost/km^2	$166./$km^2$	$60.76/$km^2$	$3.35/$km^2$@1:250,000 $29.63/$km^2$@1: 24,000	$0.95/$km^2$@1:250,000
4. Time Estimates	9 person-year per 800 km^2@ 1:24,000	4 person-year per 800 km^2@ 1:24,000	17 man-years @ 1:250,000 50 man-years @ 1:24,000 (1/3 area) for 839,300 km^2	4 person-years @ 1:250,000 for 839,000 km^2
5. Classification Accuracy	99%	90% (cultivated or bare soil) lesser accuracies in vegetated areas	95+%	85+%

we calculate that they could be reduced below operational ones if more efficient processors were used. In addition, in this case, accuracy suffers somewhat with satellite data, but speed (as measured by the number of person-years required) is greatly improved.

Soil maps benefit from satellite production techniques by reducing the need for low-altitude photography and by significantly lessening the ground survey requirements. The satellite method is slightly less accurate than the operational method, but it is faster.

Vegetative cover maps produced by satellite are approximately one-third as expensive as those produced operationally from high-altitude aircraft imagery. However, they suffer somewhat from lack of detail and accuracy. This disadvantage is mitigated by increased ability to update frequently.

In summary, we have investigated a range of products and have seen mixed benefits in using current LANDSAT data and automated processing techniques. One product, the timber volume estimate table, benefits in all three of the categories of cost, accuracy, and speed. It is produced over the large homogeneous areas (forests) most directly suited to satellite applications. The three other products: land use, vegetation, and soils maps, also show good potential for satellite application, although they benefit only in cost and speed while suffering somewhat in accuracy. These products are produced over large, but less homogeneous, areas and display many more classes than does the map of timber density constructed in producing the timber volume estimate. Thus, the three products depend more heavily on aircraft and ground survey inputs. Remember that these results were achieved with experimental, not operational, processing techniques and with LANDSAT data. We expect better accuracy performance with tested processing algorithms and LANDSAT Follow-On data.

SATELLITE-BASED SYSTEM PRODUCTION COSTS AND PERFORMANCE

To determine costs for digital production systems, we first listed the production steps involved -- from preliminary information gathering through the printing of the final product. We then searched the literature for cost estimates of each of the steps involved, or of sequences of steps when detailed cost breakdowns were unavailable. Performance figures (i.e. accuracy and timeliness) also came from the literature.

COMPARISON OF PHOTOINTERPRETIVE AND DIGITAL PRODUCTION

In general, the steps involved in producing a satellite-based information product are:

i) Preliminary work - initial search of existing information to acquaint oneself with the area to be studied

ii) Acquire data - Obtain LANDSAT Computer-Compatible Tapes (CCT's), aerial photos, and initial ground truth data. These sources provide the basic information from which the product is assembled.

iii) Process data - For satellite data this step involves five substeps:

1) Reformat CCT's
2) Geometrically correct the CCT's
3) Overlay data of differing temporal origin (where required)
4) Cluster the data
5) Maximum likelihood classification

iv) Print or output data - The printing costs for products are generally derived from published estimates or other data on output costs on peripheral devices, such as plotters.

v) Additional ground truth - Additional ground truth may also be required to verify the product quality.

Table 3 displays breakdown of costs and production times for the four products. Total cost and cost/km^2 information on the timber volume estimate table is derived nearly totally from Nichols[2], as are the accuracy figures for this product in Table 1. However, for the sake of consistency, we have made one change from Nichols' figures. He quotes a $1,207 cost for computer processing - a charge for two hours of CPU time on a Forest Service computer. We estimate, based on figures from Gaydos[3], that the same processing could be done on LARSYS in 1.64 CPU hours at a cost of $590, assuming a $6.00 per CPU min. charge for LARSYS. These estimates are interpolations of the costs Gaydos realized in using LARSYS to produce land use maps. The estimation method is described in Reference[1].

In estimating personnel times and hour costs, we have extended figures from Fitzpatrick[4] to make the following assignments:

Cartographers	$12/hr.
Photointerpreters	$20/hr.
Ground Truth Surveyors	$20/hr.
Computer Programmers	$20/hr.
Unspecified Staff	$15/hr.

These costs include overhead. Dividing Nichols'[2] total costs by these hour costs gives the man-hour estimates.

For the second product, Level II land use/land cover maps at 1:250,000 scale, we directly use Gaydos'[3] computer costs and Fitzpatrick's[4] costs for labor and printing. Fitzpatrick[4] is also the source of Table 1's accuracy figures for this product. In addition, Table 3 presents cost estimates for enlarging the map to 1:24,000 scale. Here we assume that the smaller scale map is used as a starting point, and that additional detailed aircraft and ground surveys are made to increase accuracy to that needed at the larger scale. Fitzpatrick[4] provides the basis for the cost estimates for the product at this scale.

Soil map costs and performance are from Persinger[5] and modified by us to estimate costs for 1:24,000 scale mapping. Since Persinger was a LARSYS user, we did not need to use the Gaydos[3] figures to infer computation costs on LARSYS.

Total cost and cost/km^2 figures for vegetative cover mapping are based on Poulton[6] and a discussion with Williams[7]. Computer costs are inferred from the Gaydos[3] figures. Time estimates, hour costs, and detailed breakdown of totals are ours.

COSTS OF CONVENTIONAL SYSTEMS

In a similar way, we have carried out cost estimation for photointerpretation-based systems. Table 4 displays the results, and the literature sources on which each estimate is based are cited in this table. Space does not permit a more detailed discussion; for more information, see Eastwood, et. al.[1].

COST COMPARISON FOR REGIONAL COVERAGE

In addition to comparing costs per km^2, as Table 1 does, it is also of interest to compare costs for regional coverage. In Table 5, we make this comparison for our five-state study region using the product coverage areas in Table 2.

COMPARISON OF PHOTOINTERPRETIVE AND DIGITAL PRODUCTION

Table 3

PRODUCTION COSTS FOR FOUR PRIORITY INFORMATION PRODUCTS PRODUCED BY A DIGITALLY BASED SYSTEM

Product	Step	Time	Hour Cost	Total Cost	Cost/km²*
Timber Volume Estimate Table (based on 4000 km²)	1) Obtain Data				
	a) high altitude photos	--	--	$ 200	0.05
	b) LANDSAT CCT's	--	--	$ 800	0.20
	2) Interpret Data				
	a) photo interpretor	41.25 hrs.	$20	$ 825	0.20
	b) preprocess and classify CCT's	1.64 CPU hrs.	$ 6.00/CPU minute	$ 590	0.15
	3) Sample Selected Areas with Ground Truth				
	a) low altitude photos	--	--	$ 300	0.07
	b) ground sampling	20 hrs.	$20	$ 400	0.10
	c) laboratory measurements	62 hrs.	$20	$1,240	0.30
	4) Statistical Analysis of Timber Volume	82.5 hrs.	$20	$1,650	0.41
Totals		205.75 man-hrs. + 1.64 CPU hrs.		$6,005	$ 1.48
Level II Land Use/ Land Cover Map (1:250,000)	1) Obtain Data				
	a) LANDSAT CCT's	--	--	$ 480[†]	.02
	b) Ground Truth	32 hrs.	$20	$ 640	.03
	2) Preprocess Data				
	a) Reformat	12.5 CPU minutes	6.00/CPU minute	$ 75[†]	<.01
	b) Geometrically Correct	6.82 CPU Hours	6.00/CPU minute	$2,456	.12
	3) Process Data				
	a) Classify by maximum likelihood ratio: 3 iterations	30.6 CPU Hours	6.00/CPU minute	$11,026[†]	.57
	b) Cluster classified pixels	50 CPU min.	6.00/CPU minute	$ 300[†]	.02
	c) Computer programmer	12	$20	$ 240	.01
	4) Output and Print Data	--	--	$ 1,360	.07
Totals		44 man-hrs + 38.5 CPU hrs.		$16,577	$ .84

*For 19,500 km² map sheet.

†For 0.6 of 1 LANDSAT frame.

Table 3 (continued)

PRODUCTION COSTS FOR FOUR FIDELITY DEFORESTATION PRODUCTS
PRODUCED BY A DIGITALLY BASED SYSTEM

Product	Step	Time	Hour Cost	Total/ Cost	Cost/km^2
Level II Land Use/ Land Cover Map (1:24,000) 155 km^2	1) Acquire Level II Land Use Maps enlarged to 1:24,000 scale	--	--	$ 130	.84
	2) Acquire additional ground truth	32 man hrs.	$20	$ 640	4.13
	3) Overlay and register ground truth data	10 man hrs.	$20	$ 200	1.29
	4) Print map	--	--	$ 465	3.00
Total		42 man hrs.		$1,435	$ 9.26
Soil Maps 1:24,000 scale 155 km^2/product	1) Preliminary Work	8 hrs.	$15	$ 120	.15
	2) Acquire Data				
	a) LANDSAT CCT's	--	--	$ 4*	.03
	3) Preprocess Data				
	a) Reformat tape	.2 CPU minutes	$6.00/CPU minute	$ 1*	<.01
	b) Geometric Correction	3.2 CPU minutes	$6.00/CPU minute	$ 19*	.12
	4) Process Data				
	a) Classify data by maximum likelihood	2.47 CPU min	$6.00/CPU minute	$ 15*	.10
	b) cluster classified data	.4 CPU min	$6.00/CPU minute	$ 2*	.02
	5) Output Data				
	a) On lineprinter			$ 275	.34
	6) Ground Truth	4 person years		$48,000	60.00
Totals		4 man-yrs + 6.27 CPU min.		$48,436	$60.76

*Costs figured for 1/221 of LANDSAT image (155 km^2).

Table 3 (continued)

PRODUCTION COSTS FOR FOUR PRIORITY INFORMATION PRODUCTS
PRODUCED BY A DIGITALLY BASED SYSTEM

Product	Step	Time	Hour Cost	Total/ Cost	Cost/km^2
Vegetative Cover Type Map 1:250,000 scale	1) Perform Background	65.3 hours	$15	$ 980	$ .05
	2) Acquire Data and Stratify				
	a) LANDSAT imagery	--	--	$ 40	<.01
	b) LANDSAT CCT's	--	--	$ 800	.04
	c) photo interpretation	62.5 hours	$20	$ 1,250	.06
	d) ground truth	32 hours	$20	$ 640	.03
	3) Perform First Subsampling of Data				
	a) preprocess CCT's	7.0 CPU hours	$6/CPU minute	$ 2,531*	.13
	b) 16 class clustering on training cells (13% of area)	50 CPU min.	$6/CPU minute	$ 309*	.02
	c) Computer programmer	12 hours	$20	$ 240	.01
	4) Select Support System and Staging				
	a) aerial photograph 2% total area high altitude CIR			$ 2,200	.11
	2% total area medium altitude CIR			$ 2,350	.11
	b) additional ground truth	80 hrs	$20	$ 160	<.01
	5) Perform Refined Interpretation				
	a) maximum likelihood classification over entire area: 3 iterations	16.41 CPU hours	$6/CPU minute	$ 5,907*	.31
	b) programmer	12 hours	$20	$ 240	.01
	6) Print Map			$ 1,360	.07
Total		191.8 man hrs + 24.2 CPU hrs		$18,798	$ .95

*Costs figured for .6 LANDSAT image.

Table 4

PRODUCTION COSTS FOR FOUR PRIORITY PRODUCTS PRODUCED BY A PHOTOINTERPRETATION BASED SYSTEM

Product	Step	Time	Hour Cost	Total Cost	Cost/km²
Level II Land Use[4] Map 1:250,000 Scale @ 19,500 km² sheet	1) Acquire Data H/A A/C coverage	--	--	$ 975	.05
	2) Mosaicking	156 hrs.	$20	$ 3,120	.16
	3) Interpretation	488 hrs.	$20	$ 9,760	.50
	4) Cartographic Compilation	156 hrs.	$12	$ 2,150	.11
	5) Reproduction and Printing	--	--	$ 1,365	.07
Totals		890 person hrs.		$17,370	.88
Level II Land Use[4] Map 1:24,000 Scale 155 km²	1) Acquire Data	--	--	$ 22	.14
	2) Mosaicking	46.5 hrs.	$20	$ 930	6.00
	3) Interpretation	9.3 hrs.	$20	$ 185	1.20
	4) Cartographic	3.1 hrs.	$12	$ 28	.74
				$ 194	1.25
	5) Production and Printing	--	--	$ 480	3.10
Totals		59 person hrs.		$ 1,850	$11.93
Timber Volume[2,8] Estimate Tables	1) Acquire imagery medium altitude A/C, BW & IR			273,000	5.29
	2) Field work (45% of total inventory costs, includes expenses	8 person/yrs[θ]	$25/hr[θ]	410,000	7.95
	3) Compilation, Interpretation and Processing	4 person/yrs[θ]	$15/hr[θ]	112,000	2.17
Totals		12 person years		$755,000	$15.41
Soil Maps[9] 1:24,000 Scale (155 km²)	1) Acquire Data			$ 1,300	8.68
	2) Interpretation			$ 5,100	33.20
	3) Compilation			$ 2,600	16.60
	4) Field work			$16,200	104.58
Totals		1.75 person year		$25,200	$166.16

*Based on 1972 Forest Inventory of Missouri for 51,700 km².

θTime and hour cost our estimates.

Table 4 (continued)

PRODUCTION COSTS FOR FOUR PRIORITY PRODUCTS PRODUCED BY A PHOTOINTERPRETATION BASED SYSTEM

Product	Step	Time	Hour Cost	Total Cost	Cost/km^2
Vegetative Cover Maps 1:250,000 scale[10]	1) Perform Background work	49 hrs.	$20	$ 980	.05
	2) Acquire, interpret and register imagery				
	a) N/A A/C CIR (stereo)			$49,000	2.51
	b) Mosaicking	240 hrs.	$20	$ 4,800	.25
	c) Interpretation	240 hrs.	$20	$ 4,800	.25
	3) Perform Field Survey	160 hrs.	$20	$ 3,200	.16
	4) Compile map	100 hrs.	$12	$ 1,200	.06
	5) Printing Map	--	--	$ 1,365	.08
Totals		838 person hrs.		$65,345	3.35
Vegetative Cover Maps 1:24,000 scale[10]	1) Perform Background work	--	--	$ 00	.05
	2) Acquire imagery CIR stereo 1:20,000 scale	--	--	$ 840	5.42
	3) Interpret and Register Imagery	17.25 hrs.	$20	$ 385	
	4) Perform Field Survey	96 hrs.	$20	$1,920	12.39
	5) Compile Map	80 hrs.	$12	$ 960	6.19
	6) Print Map	--	--	$ 480	3.10
Totals		195.25 person hrs.		$4,593	$29.63

Table 5

COMPARATIVE COSTS FOR ANNUAL COVERAGE BY TWO ALTERNATIVE PRODUCTION SYSTEMS FOR FOUR PRIORITY INFORMATION PRODUCTS

Product	Coverage	Aircraft System Annual Cost	Satellite-Based System Annual Cost	% Change
Timber Volume Estimate Table	51,770 km^2	$ 798,000	84,400	-89.4
Level II Land Use/Land Cover Map				
1:250,000	167,000 km^2	$ 147,000	213,760	+45
1:24,000	8,350 km^2	100,000	81,000	-19
Soil Maps 1:24,000 scale	41,750	$ 6,940,000	2,710,000	-60.9
Vegetative Cover Map 1:250,000 Scale	835,000 km^2	$ 2,800,000	977,000	-65.1
Total		$10,785,000	4,071,160	-62.3

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